Causes of mortality and pathologic findings in Pacific Island cetaceans: A review of strandings from 2006-2022

Kristi West[1], Ilse Silva-Krott[1], David Rotstein[2], Gregg Levine[3]

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[1]Human Nutrition Food and Animal Sciences, College of Tropical Agriculture and Human Resources, Honolulu, HI 96822, USA
[2]Marine Mammal Pathology Services, Olney, MD 20832, USA
[3]National Oceanic Atmospheric Administration. Pacific Island Regional Office, Honolulu, HI 96818

Running Header
Cetacean strandings in Pacific Islands 2006-2022

ABSTRACT

We report significant pathological findings from 250 stranding investigations of 20 cetacean species in the Pacific Islands region between 2006 and 2022. Full or partial necropsies of 196 of the 250 stranding cases (78.4%) resulted in a diagnosis or multiple diagnoses associated with death in 126 cases. Natural disease accounted for 60.3% of stranded animals; approximately half were in poor body condition at time of death due to chronic illness. Morbillivirus and *Brucella* sp. infections caused mortality in eleven species, including striped dolphins and the Longman's beaked whale. *Toxoplasma* infection, of anthropogenic cause in Hawai‘i, led to the deaths of two spinner dolphins. Pygmy and dwarf sperm whales, beaked whales and pilot whales showed heavy parasitism by nematodes, cestodes and trematodes. Approximately 12.7% of stranded individuals were perinates/neonates, with three cases of dystocia with maternal mortality. Anthropogenic trauma was observed in 30.2% of strandings. In seven Cuvier's beaked whales, cranial and/or microvascular hemorrhages were categorized as trauma. Vertebral and skull fractures were attributed to direct vessel strikes for two pygmy sperm whales, a Cuvier's beaked whale, a humpback whale calf and a striped dolphin. Blast trauma was observed in three Fraser's dolphins that were part of an uncommon stranding event. Significant plastic debris, and/or fishery debris were found in stomachs of six species and fatal fishhook penetration occurred in a bottlenose dolphin. This study highlights the value of carcass examinations in a region inhabited by small island associated populations where carcass recovery rates are low, and cetaceans face an array of natural and anthropogenic threats.

KEY WORDS

Cause of death, mortality, pathology, cetacean, disease, trauma, fishery interaction

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
09-09-2024

2. REPORT TYPE
Monitoring report

3. DATES COVERED *(From - To)*
2006 to 2022

4. TITLE AND SUBTITLE
CAUSES OF MORTALITY AND PATHOLOGIC FINDINGS IN PACIFIC ISLAND CETACEANS: A REVIEW OF STRANDINGS FROM 2006-2022

5a. CONTRACT NUMBER
N62473-20-2-0001

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Kristi L. West
Ilse Silva-Krott
David Rotstein
Gregg Levine

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Human Nutrition Food and Animal Sciences, College of Tropical Agriculture and Human Resources, Honolulu, HI 96822, USA

Marine Mammal Pathology Services, Olney, MD 20832, USA

National Oceanic Atmospheric Administration. Pacific Island Regional Office, Honolulu, HI 96818

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Commander, U.S.Pacific Fleet, 250 Makalapa Dr. Pearl Harbor, HI

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSORING/MONITORING AGENCY REPORT NUMBER

12. DISTRIBUTION AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited

13. SUPPLEMENTARY NOTES

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15. SUBJECT TERMS
Marine mammals, strandings, necropsy, disease, cetaceans, Hawaii Range Complex, Mariana Islands Rangle Complex, Pacific Islands Region

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT Unclassified	**b. ABSTRACT** Unclassified	**c. THIS PAGE** Unclassified	UU	55	Department of the Navy
					19b. TELEPONE NUMBER (*Include area code*) 808-471-6391

1. INTRODUCTION

The Pacific Islands region spans over 4 million square miles across the central, Western, and South Pacific, and stranding investigations are routinely conducted for cetaceans stranding in the Hawaiian Islands, the Mariana Islands and in American Samoa. At least twenty species of cetaceans regularly inhabit the Hawaiian archipelago (Baird 2016), with 13 species of cetaceans described from the Mariana Islands (Fulling et al. 2011) and 11 species of cetaceans have been identified to date from American Samoa from strandings and sightings (Walsh & Paton 2003, Johnston et al. 2008, Bradford and Forney 2014, West unpublished data, Tagarino Pers. Comm.). Natural causes of death include infectious disease which is a significant threat to Pacific Island cetaceans (Rotstein et al. 2010, West et al. 2013, West et al. 2021). Anthropogenic impacts that cause cetacean mortality as determined from stranding investigations are well described in the scientific literature from other regions. These include marine debris ingestion and entanglements with mortalities due to gastric blockages reported in sperm whales (*Physeter macrocephalus*), Cuvier's beaked whales (*Ziphius cavirostris*) and Risso's dolphins (*Grampus griseus*) (Jacobsen et al. 2010, Alexiadou et al. 2019). Sperm and fin whales (*Balaenoptera physalus*), with diverse foraging strategies, have been suggested as potential indicators of global marine litter (Fossi et al. 2020). National disentanglement programs highlight the impact of entanglements on mortality and morbidity of cetaceans world-wide, with this threat included as one of the initiatives of the International Whaling Commission. Cetacean mortalities due to by-catch and lethal fishing hook penetration have also been described (Adimey et al. 2014, Byard et al. 2020, Cuvertoret-Sanz et al. 2020). Vessel strikes provide another example of fatal anthropogenic impacts to cetaceans, with mortalities described from oceans world-wide (Diaz-Delgado et al. 2018, Peel et al. 2018, Peltier et al. 2019, Pennino et al. 2022, Sharp et al. 2018, Womersley et al, 2023). Naval sonar and echosounders can also result in strandings, with beaked whales believed to be especially vulnerable to anthropogenic noise (Southall et al. 2013, Bernado de Quiros et al. 2019, Simonis et al. 2020). Carcass recovery of cetaceans is low as many animals die out at sea and do not strand. However, when carcasses are recovered critical data is collected and analyzed that provides insight into morbidity, mortality and population health. Extensive necropsies are conducted that deliver detailed information through gross, and histopathological findings, in addition to ancillary testing to detect infectious disease and diagnostic imaging.

Pathological findings in stranded cetaceans have been described according to natural and anthropogenic causes of mortality from several regions of the world (i.e., Arbelo et al. 2013, Delgado-Diaz et al. 2018, Alvorado-Rybak et al. 2020, Cuvertoret-Sanz et al. 2020, Burek-Huntington et al. 2022, Souter et al. 20024). In the Pacific Islands region, pathological findings from individual stranding investigations have been described and important disease threats identified (i.e. West et al. 2013, West et al. 2015, West et al. 2021, Rotstein et al. 2010, Landrau-Giovannetti et al. 2022, Clifton et al. 2023). A systematic examination of abnormal findings and quantification of observed causes of mortality has not previously been conducted for the Pacific Islands region. Our objective was to re-examine stranding cases occurring between 2006 and 2022 throughout the Pacific Islands region (Hawaiian Islands, U.S. territories and one case from the Federated States of Micronesia). This report focuses on findings from 64% of the stranding cases (125 of 196) where partial or full necropsies were conducted and where one or several significant diagnoses were obtained from gross necropsies, histopathological evaluation, and/or ancillary tests.

2. MATERIALS & METHODS

The University of Hawai‘i Health and Stranding Lab, formerly operating at Hawai‘i Pacific University, was involved in 250 stranding investigations representing 20 different species of whales and dolphins between 2006 and 2022. These include strandings occurring in the main Hawaiian Islands, the Northwestern Hawaiian Islands, the Mariana Islands, American Samoa, Wake Island and an individual that stranded in the Federated States of Micronesia.

Stranding cases that were included in this systematic re-examination include all stranded specimens where either minimal external soft tissue was sampled, such as skin, muscle, blubber, and/or bone and where partial or full necropsies were conducted. All carcasses were assigned condition codes 1 to 5 to estimate autolysis following the method described by Geraci & Lounsbury (2005). Of the 250 cases examined, 54 of the cases (21.6%) involved minimal tissue sampling of 1-4 tissues (typically external tissues or bone) and/or did not include examination of internal body cavities. Partial necropsies for this study are defined by at least a partial examination of internal organs within body cavities and the collection of a minimum of 5 different tissue types. Full necropsies involved an examination of all major organ systems and extensive tissue sampling. Full or partial necropsies were conducted for 196 of the 250 cases examined (78.4%). Partial or full necropsies were conducted in almost all cases of smaller odontocetes. Partial or full necropsies were uncommon in mid to large sized odontocete and mysticete strandings where size, remote stranding locations, and access to floating carcasses and/or human safety concerns limited the ability to conduct necropsies. These limitations were most extreme in the examination of sperm whale strandings, where 27 individuals were confirmed stranded with minimal tissue samples collected, but partial or full necropsies were only conducted for five of these cases (18.5%). In all cases, tissues were archived and curated for future applications, such as studies aimed at better understanding cetacean genetics, toxicology and endocrinology.

Necropsies were carried out at the Health and Stranding Lab whenever possible to increase the quality of the data collected and preservation of tissues. In some cases, necropsies were conducted in the field when carcass size or a lack of air cargo transportation limited our ability to necropsy within a sterile lab setting. Necropsy examination and tissue sampling followed standard protocols (Pugliares et al. 2007, IJesseldijk et al. 2019).

Animals were assigned to age classes (perinatal, calf, subadult, adult) based on body length, fetal folds, whiskers, sexual maturity and/or dental age (Gerarci & Lounsbury 1993). Fetuses were not counted as individual stranding cases but are included in the pathology summary table if dystocia was present. In the case of code 1, 2 and 3 animals, body condition was assessed by physical examination of observed robustness that included documentation of a visible depression behind the skull or bones that could be observed under the skin, weight/length ratios and blubber histology metrics (IJsseldijk et al. 2019, Phipps et al. 2023). Blood was collected from the tail vein, and/or aorta or heart whenever possible. Blood was collected ante-mortem from 25 live stranded animals. Blood samples were collected in vacutainer tubes and centrifuged before freezing blood serum at -80ºC. Cerebrospinal fluid was collected by dorsal puncture at the atlanto-occipital joint and frozen for analysis. Histopathology samples were fixed in 10% buffered formalin, embedded in paraffin and 5 µm sections were stained with hematoxylin and eosin (H&E). Selected histopathological sections (4-10 µm thick) were stained using the Gram/Tword method to characterize bacterial pathogens and Periodic acid Schiff and Grocott-Gomori's Methenamine Silver stains were used to demonstrate fungal pathogens. Immunohistochemical staining methods were used to detect viral proteins of cetacean morbillivirus and protozoal protein of *Toxoplasma gondii* in tissue sections of cases that tested positive using molecular methods (PCR, RT-PCR) (Miller et al. 2001, West et al. 2013, Landrau-Giovannetti et al. 2022). Circovirus was demonstrated in tissues by in-situ hybridization after RT-PCR amplification and sequencing results were obtained (Landrau-Giovanetti et al. 2020). Selected tissue samples were tested for the presence of herpesvirus DNA by PCR.

Samples of all lesions and tissues of organs, and collected sperm, milk, gastrointestinal content, urine, and aqueous humor were frozen in cryovials at -80ºC for molecular analysis. Lesions of dead animals were described and examined based on previously described criteria (Moore et al. 2013; Bernaldo de Quiros et al. 2019). A portable x-ray machine was used to investigate bone injury or injury associated with suspected fishery interaction. This included ingested hooks in two cases, a false killer whale and a bottlenose dolphin, as well as to image the full carcass in select cases. X-ray imaging was conducted of localized areas in some cases where blunt trauma was suspected at local medical facilities. Computed tomography (CT) scans were carried out for 10 different species and included nine full body CT scans in the case of smaller specimens and nine heads for small to medium-sized whales.

Cetacean deaths were generally categorized into two main causes that included natural disease and trauma. Fatally disseminated toxoplasmosis was considered of anthropogenic cause in Hawaiʻi (Harting et al. 2020). Natural cause of death was categorized further as natural (good nutrition), natural (poor nutrition), and perinatal/neonatal. Traumas were further categorized into five types of trauma: 1) Blunt trauma that includes blast trauma where blunt trauma is characterized by internal hemorrhage, edema and other soft tissue damage and fractures due to direct impact such as vessel collisions or impact from pressure or sound that originate from air-guns or sonar; 2) Fishery by-catch; 3) Fishery injury caused by hooks; 4) Ingestion of netting or gunshot, entanglement and entrapment that is the result of restrictive changes that limit the ability of the animal to surface to breathe such as being caught in fishing gear and 5) Decompression sickness.

3. RESULTS

Of the total 250 stranding investigations conducted, 140 cases were carcass condition codes 1 and 2, 107 cases were condition codes 3, 4, or 5. Carcass condition was not determined in three cases. Full or partial necropsies were conducted for 196 of the 250 cases (78% examined). Animals examined by necropsy included 18 different odontocete species and one mysticete species, humpback whale (*Megaptera novaeangliae*). Table 1 provides an overview of species examined including sex, age class and necropsy status. Table 2 summarizes species and findings by categories that includes natural causes of death and traumas. A summary of pathological findings by species are described below and Tables 3, 4, 5 and 6 provide examples of significant pathological findings. In some cases, pathological findings resulted in cause of death and in others significant pathological findings were present that are believed to be incidental and did not result in mortality.

Pygmy killer whales (Feresa attenuata)

Full necropsies were conducted for each of the ten pygmy killer whales dead stranded between 2006 and 2022 with significant pathological findings observed in 8 of the 10 cases (Table 2). Seven of these individuals were part of a prolonged mass stranding event in Māʻalaea Bay, Maui, in 2019. During this prolonged mass stranding event, five individuals in good body condition were necropsied with pathological findings identified in four animals (Table 3). Two additional individuals were monitored out of habitat for a several weeklong period where body condition declined prior to eventually stranding (Currie et al. 2021). The first animal that stranded dead was a calf on the first day of the prolonged mass stranding event. The predominant lesions indicated pyogranulomatous bronchopneumonia and meningoencephalitis. Four animals tested positive for *Brucella* sp. by PCR (Silva-Krott et al. Submitted). Respiratory disease was the significant pathological finding in a calf that stranded in 2015. An earlier stranding of a single individual in 2009 also occurred in Māʻalaea Bay, Maui and was the result of a group of 4-6 animals initially out of habitat that were monitored over time while the group size steadily declined until a single individual stranded. Pneumonia was the cause of death in the individual that stranded in 2009. Two pygmy killer whales were solitary stranding events off Oʻahu and Hawaiʻi Island. One animal had scars along the mouth and the esophagus consistent with fishery interaction. Incidental scoliosis was documented in this animal. In 40% of the total cases examined (4/10), pneumonia secondary to bacterial and viral infection caused death. Animals in poor body condition had neurobrucellosis in two cases and metabolic disease in one case. In addition to *Brucella* sp., morbillivirus RNA was identified by PCR analysis of a lymph node in one case, and sequencing of this pathogen indicated close genetic similarity to the recently described Fraser's dolphin (*Lagenodelphis hosei*) morbillivirus (West et al. 2022).

Pilot whales (Globicephala macrorhynchus)

Short-finned pilot whales strandings in the Pacific Islands region between 2006 and 2022 are represented by both solitary strandings and a mass stranding event that occurred off the island of Kauaʻi in 2017. Partial or full necropsies were conducted for 11 of the 17 pilot whales that were stranded during the time period examined. In the 2017 mass stranding event, five individuals were necropsied with histopathology and disease screening conducted. The cause of the stranding was not determined despite describing approximately 6 kg of marine debris from the stomach of one of the male individuals and pathological changes in the abdominal cavity of an older adult female that may have been associated with trauma during the stranding event. Significant marine debris ingestion (>4,500 grams) was noted in two additional solitary stranded individuals but did not cause fatal intestinal blockages. Pterygoid verminous sinusitis and intestinal nematodiasis were common in stranded pilot whales in the main Hawaiian Islands. A recently stranded calf in 2022 died of verminous bronchopneumonia (*Halocercus* sp.). Limited samples were obtained from six cases due to advanced decomposition and/or remote location of stranding.

Risso's dolphins (Grampus griseus)

Risso's dolphins are a pelagic species that rarely strand in the Pacific Islands region. Between 2006 and 2022, three carcasses were examined. One of these was in an advanced state of decomposition and was identified from the skull and tooth counts. The other two individuals were fresh, dead carcasses. One was recovered as by-catch in a known fishery interaction. The other was in poor nutritional status and had dilated cardiomyopathy. This individual also had heavy parasitosis of the liver and stomach (Table 4), and an incidental finding included the recovery of a plastic bag from the esophagus of the animal.

Pygmy sperm whales (Kogia breviceps)

Pygmy sperm whales are deep diving small whales with a world-wide distribution. Pathological changes were documented in 13 out of 19 pygmy sperm whale strandings. Six pygmy sperm whale deaths were associated with acute death, secondary to trauma, including five cases of blunt trauma (Table 5). In one case, the animal had a fractured cervical vertebrae and severe decompression sickness (Figure 1). Cardiac disease has been described in pygmy sperm whales from other regions of the world (Bossart et al. 2007). Two cases of cardiomyopathy, including cardiac tamponade leading to sudden death in a pregnant female (Figure 1), were documented during the time period examined. Necropsied animals had moderate to severe endoparasitism regardless of body condition, consisting of gastrointestinal nematodes and subcutaneous phyllobothria.

Dwarf sperm whales (Kogia sima)

Significant pathologic changes were documented in three of the eight dwarf sperm whale cases including one case of entrapment (Table 3, Table 4, Table 5). Cardiac hypertrophy and multifocal myocardial fibrosis were found in a pregnant animal in good body condition, and another pregnant animal died from bronchopneumonia and septicemia.

Longman's beaked whale (Indopacetus pacificus)

Longman's beaked whales are one of the world's most poorly known beaked whale species and rarely strand. There is only one confirmed case of a Longman's beaked whale stranding in the Pacific Islands that occurred in Hana, Maui, in 2010. The animal had fractures of the mandible and maxilla, determined to be peri-mortem and were likely associated with stranding-related trauma. Multiple fresh cookie cutter shark bites were also noted on the abdomen. Histopathological examination revealed multi-organ inflammation. The cetacean had novel beaked whale morbillivirus and alpha herpesvirus (West et al. 2013), the first described circovirus in a marine mammal (Landrau-Giovanetti et al. 2020), and later tested positive for *Brucella* sp. (West, unpublished data).

Fraser's dolphins (Lagenodelphis hosei)

Fraser's dolphins are pelagic pantropical dolphins, and stranding events of this species are rare. However, despite a historical infrequency of stranding in the Pacific Islands, we conducted full necropsies for seven Fraser's dolphins that were stranded between 2018-2022 and documented significant findings in all cases (Table 5). In 2018 a Fraser's dolphin stranded on Maui was infected by a novel morbillivirus named Fraser's Dolphin morbillivirus (West et al. 2021). Additional pathogen screening identified *Brucella* sp. and circovirus. Another adult female animal with signs of infectious disease which tested positive for circovirus stranded in 2021 on Hawaiʻi Island. A male stranded in 2022 off Maui had granulomatous dermatitis caused by the fungus, *Paracoccidioidis spp.,* the pathogen that causes lobomycosis-like disease (St. Leger et al. 2018). This is the first time that this fungus has been reported in the central Pacific, with prior cases of lobomycosis-like disease in dolphins known from the Atlantic coast and from Central America (Bermudez et al. 2009, Rotstein et al. 2009, Bossart et al. 2017, Galvez et al. 2022). A mass stranding of three Fraser's dolphins within 2 miles over a 2-day period occurred in 2021 off the island of Oʻahu, meeting the criteria for an Uncommon Stranding Event. All three animals were in good nutritional condition. These necropsied individuals had multiple hemorrhages across organ systems and ear and mandibular fractures, consistent with blast trauma (Siebert et al. 2022). Another Fraser's dolphin that stranded dead in Guam and was necropsied had an entry and exit wound consistent with a gunshot wound. A projectile was not recovered, and an x-ray was not conducted.

Humpback whales (Megaptera novaeangliae)

Similar circumstances that limit cause of death investigations for sperm whales also apply to humpback whales and include advanced decomposition, floating carcasses, and large size, with strandings in remote areas or along shorelines that are inaccessible with heavy equipment. Out of 25 stranding events where at least one tissue sample was collected from stranded humpback whales, full necropsies were possible in 15 cases (60%) and partial necropsies in two cases (8%) between 2006 and 2022. Of the 25 stranding investigations, five involved neonates. One of these cases represented a breech birth resulting in dystocia, that was the likely cause of death for both the mother and calf. In this same event, calf tissues tested positive for *Brucella* sp., representing vertical transmission from the mother that was in a moderate to advanced state of decomposition. Another case involving a neonate in 2022 off Oʻahu had cerebral hemorrhage and evidence of a concussive blunt force trauma that led to death, most likely caused by a vessel strike. Another humpback whale calf died of septicemia, but the animal also had a costal rib fracture. It is possible that the septicemia was secondary to immunosuppression caused by another pathogen.

Blainville's beaked whale (Mesoplodon densirostris)

Blainville's beaked whales occasionally strand in the Pacific Islands region, and a total of five strandings have been recorded between 2006 and 2022. Partial necropsies were conducted for two individuals stranded at Midway Atoll and in American Samoa, and another necropsy was attempted, but only minimal samples were collected from an individual in an advanced state of decomposition in American Samoa. Full necropsies were conducted on two individuals in the main Hawaiian Islands. Cause of death could not be determined in four of the five cases due to moderate to advanced decomposition of the carcasses. Multi-system organ disease was responsible for the death of one of the whales, initially stranded alive on Maui in 2010, where rehabilitation was attempted at the University of Hawaiʻi at Hilo. Significant findings included pyogranulomatous pneumonia, perforating gastritis and acute nephropathy. Fungal organisms (*Aspergillus)* were noted in the lung and associated with airways and blood vessels. PCR tests indicated the presence of circovirus DNA in multiple organs and morbillivirus RNA in a small number of a suite of tissues tested (Jacob et al. 2016, Clifton et al. 2023).

<u>*Killer whales (Orcinus orca)*</u>

Hawaiʻi has a small population of killer whales that are infrequently sighted and even more infrequently strand. Between 2006 and 2022, one live killer whale that was euthanized stranded in 2008 off Kauaʻi, A skull was also recovered during this period from a killer whale on Lānaʻi but is believed to have surfaced years after the burial of a 2004 stranding of a killer whale near the site of the recovered skull. The necropsied killer whale that stranded in 2008 was in poor body condition. The gross necropsy and histopathology findings were not conclusive but suggested metabolic or inflammatory disease with a proximate cause of death determined as emaciation (Raverty et al. 2020).

<u>*Melon-headed whales (Peponocephala electra)*</u>

During the 2006 to 2022 time period, 20 melon-headed whale stranding investigations were conducted, with 18 of these animals stranded in the main Hawaiian Islands, one stranding in Guam, and another in the Federated States of Micronesia. From these strandings, partial or full necropsies were conducted for 18 individuals. Cause of death was undetermined in nine of these cases. Two cases were associated with perinatal or neonatal mortality (Table 6). Natural disease associated with poor nutritional status was found in five cases (Table 4). A heavy parasitic load, especially nematodiasis in pterygoid sinuses, was observed in several individuals. Two animals in good nutritional status had infectious respiratory disease, and lymphadenopathy was noted in one case.

Respiratory disease, specifically interstitial pneumonia, moderate and subacute to chronic, was found most frequently among animals dying of natural disease. PCR diagnostic tests of lung, brain and lymph node tissue did not detect *Brucella* sp., morbillivirus and herpesvirus. One case tested positive for *Mycoplasma* sp. in a lung sample, the first reported case of a *Mycoplasma* infection in a cetacean from the central Pacific (West, unpublished data).

Sperm whales (Physeter macrocephalus)

Partial or full necropsies were conducted for 5 of 27 stranded sperm whales because of a combination of advanced decomposition, strandings in remote locations or floating carcasses and/or logistical challenges, a lack of heavy equipment access and/or human safety concerns. Two of the five partial necropsies were carcasses in advanced states of decomposition, and cause of death is unknown. Partial necropsies of two calves included a stranded animal where cause of death is unknown. The other stranded dead calf was moderately decomposed but inflammatory processes were identified in the umbilicus and the lung with a large number of intralesional bacterial cocci and infectious disease is suspected in this case. A perinatal calf that was stranded in 2011 off Oʻahu allowed for a full necropsy and comprehensive investigation. This individual initially tested positive for a *Brucella* sp. and morbillivirus co-infection (West et al. 2015) and cause of death was attributed to brucellosis. Since this report, this same individual has also tested positive for a gamma herpesvirus and circovirus, that may have contributed to immunosuppression, leading to overwhelming infection (West, unpublished data, Clifton et al. 2023).

False killer whales (Pseudorca crassidens)

False killer whales in the Pacific Islands include an endangered insular main Hawaiian Islands population, where most recent abundance estimates suggest only 138 individuals remain (Badger et al. 2023). Six individuals were examined and necropsied from the insular main Hawaiian island population between 2006 and 2022, and two individuals were necropsied that were not insular false killer whales. A pelagic false killer whale that died from its tail being wrapped in fishing line was recovered by the NOAA/NMFS Pacific Islands Region Fishery Observer Program and necropsied, and a partial necropsy was conducted for a false killer whale that stranded in Rota, Commonwealth of the Northern Mariana Islands, during this period. All of the six individuals examined from the insular main Hawaiian population were adults, with only one of these not identified using the Cascadia Research Collective photo identification catalog for this endangered population (Bradford et al. 2018, Mahaffy et al. 2023). One died from cardiac failure, and another was extremely emaciated with changes consistent with chronic heart valvular endocardiosis, pneumonia and adrenalitis. Inflammatory and necrotic changes in organs are consistent with an infectious etiology. PCR of multiple organs has not detected herpesvirus, morbillivirus or *Brucella* sp. Another adult animal died of pulmonary embolism derived from a large thrombus in the right atrium. Verminous pterygoid sinusitis was observed in two cases, and one had a severe intestinal infection with *Acantocephalus* sp. Incidental findings that were not associated with cause of death include the ingestion of fishing hooks in two of the animals from the insular main Hawaiian Islands population, other debris ingestion, including a laundry soap cap and water bottle, and ingestion of a fishing hook and gear in the pelagic false killer whale that died from its tail being wrapped in line.

Spotted dolphins (Stenella attenuata)

Pantropical spotted dolphin strandings are rare throughout the Pacific Islands region. Cause of death investigations have been conducted for a total of seven partial or fully necropsied spotted dolphins in the region that stranded between 2006 and 2022. Two cases were strandings from Guam, one was a calf, and the other was an adult female and unborn calf that both died from dystocia (Table 1). Two of the strandings from the main Hawaiian Islands represent animals whose cause of death is related to verminous pneumonia. One of these individuals was emaciated and the lungworm present was identified as *Halocerus* sp. This animal also had significant bone disease apparent in thoracic and caudal vertebrae and in the ribs and suffered from renal disease. Two of the spotted dolphins examined had evidence of trauma and include a calf with signs of blunt trauma to the side of the head, and decompression sickness was observed in multiple organ systems. A spotted dolphin was recovered by the NOAA/NMFS Pacific Islands Fishery Observer program near the main Hawaiian Islands following a fatal fishery interaction and another stranding had unknown cause of death.

Striped dolphins (Stenella coeruleoalba)

Between 2006 and 2022, 26 strandings of Pacific Island striped dolphins were recorded, and 57% (15/26) of these individuals suffered from natural disease. In eight cases, animals were in poor body condition, indicative of chronic disease. Neurobrucellosis and infectious bronchopneumonia were diagnosed in eleven out of fifteen total cases with natural disease. *Brucella* sp. infection was detected by PCR in eight different species to date (West et al. 2022), but striped dolphins have a high frequency of testing positive for this pathogen in the Hawaiian Islands. This includes three positive striped dolphins stranding within a 26-day period in 2021 with pathological changes in the brain consistent with severe infection in two of the three animals that were fresh dead and allowed for histopathological examination. Fusion of the atlanto-occipital joint was observed in three striped dolphins, which is indicative of significant bone disease that may be a direct result of *Brucella* sp. infection (Dagleish et al. 2007). We also report on a blunt trauma death with skull fractures consistent with a vessel strike in a stranded striped dolphin. Incidental findings in this species include healed lesions documented at the time of necropsy that are consistent with prior fishery interactions.

Spinner dolphins (Stenella longirostris)

Partial or full necropsies were conducted for 38 spinner dolphins out of a total of 42 stranded specimens of this species over the time period examined (2006-2022). Spinner dolphins are near-shore residents in Hawaiian waters, and therefore we anticipate that a greater number of strandings were publicly reported and observed when compared to pelagic cetacean species. Trauma led to death in four cases and included blunt trauma and abdominal injury likely due to a harpoon. Changes consistent with entrapment were found in two cases. Infectious diseases identified in this species include fatally disseminated toxoplasmosis, brucellosis, herpesvirus infection and systemic cryptococcosis. In isolated spinner dolphin stranding cases, we observed a gastro-intestinal stricture that likely led to the death of one animal, dystocia that likely resulted in the deaths of mother and calf, an entanglement that led to peracute underwater entrapment, and a lethal fishery interaction. We also report on a case of atlanto-occipital fusion in a spinner dolphin that represents significant bone disease and our first observation outside of striped dolphins.

Rough-toothed dolphin (Steno bredanensis)

Full necropsies were conducted on three individuals and the head was examined from a fourth individual. Two of the full necropsies were by-caught rough-toothed dolphins in American Samoa and examined by the NOAA/NMFS Pacific Islands Fishery Observer program. An adult skull was recovered from inside of a large fishing net on Maui and represents entanglement. The other full necropsy was of a fresh, dead stranded specimen that had orchitis and died of septicemia. Bacteria were confirmed in lesions examined and alcaligenes bacteria were cultured from samples. The septicemia that caused the death of this individual may have been secondary to immunosuppression by another pathogen.

Bottlenose dolphins (Tursiops truncatus)

During the period between 2006 and 2022, four stranded bottlenose dolphins were examined, with all of these individuals stranding in the main Hawaiian Islands. Bacterial disease and endotoxemia were diagnosed in a bottlenose dolphin in good body condition and *Salmonella* sp. was cultured from a liver sample. An x-ray image of a stranded animal in moderate decomposition revealed an ingested fishhook lodged in the esophagus of the animal. Necropsy confirmed the fishhook had penetrated the esophageal wall. The fishhook ingestion in this case was believed to be lethal (Table 5).

Cuvier's beaked whales (Ziphius cavirostris)

Twelve Cuvier's beaked whale strandings were investigated in the Pacific Islands between 2006 and 2022. These stranding locations spanned the main Hawaiian Islands, American Samoa, Guam, Saipan, and Wake Island and partial or full necropsies were conducted in eight of these cases and a head with significant pathology was also examined. In six cases, hemorrhages in meninges, cerebrum and/or microvascular hemorrhages were noted (Table 5). A cervical vertebral fracture caused death in another case that was categorized as trauma (Table 5). Significant renal parasitism by *Crassicauda* sp. was documented in five of the adult cases examined and one of these animals also had bronchopneumonia (Table 2, Table 3). The parasitism was so severe that it was initially thought to contribute to stranding. However, Baird's beaked whales taken in a Japanese fishery also exhibited extreme renal parasitism in almost all healthy individuals examined (Robert Brownell Pers. Comm.). No significant pathological findings were apparent in 4 cases, sometimes due to advanced decomposition or minimal sampling.

4. DISCUSSION

Pathological findings from 126 cases had a significant diagnosis or diagnoses (Tables 3, 4 and 5). Natural disease was significant in 60.3% of stranded animals, close to half of the individuals where significant natural disease was identified were in poor body condition due to chronic illness. Approximately 12.7% of stranded individuals across all species examined were in the perinatal/neonatal age group, with three cases of dystocia where the mother and calf died. All traumas that were observed were attributed to anthropogenic impacts for the purpose of this study. However, it is possible that trauma could have resulted from extreme intra-species or inter-species aggression. Trauma was observed in 30.2% of cases with pathologic findings and 39.5% of those cases were fishery interactions (bycatch, hook injury, gun shot, ingestion of netting, entanglement and entrapment). Blunt trauma was responsible for mortality in 50% of the cases categorized as trauma, primarily believed to be a result of boat strikes and blast injuries. Significant changes suggesting decompression sickness were noted in 10.4% of the cases categorized as trauma when all species were examined collectively.

4.1 Disease

Significant disease was detected in 61.9% of all examined animals but did not necessarily lead directly to mortality in all cases. The incidence of infectious disease in stranded cetaceans was similar in other geographic regions including the Canary Islands and in Italy (Giorda et al. 2017, Diaz-Delgado et al. 2018). Sublethal infections contribute to additive stress that ultimately cause immunosuppression and increased susceptibility to severe disease by opportunistic pathogens such as fungi and commensal bacteria. Most cetacean species are highly social with multiple cetacean species documented in mixed pods in Hawaiian waters (Baird 2016), providing opportunity for transmission of pathogens both between and within species. Pathogen reservoirs and routes of transmission are poorly understood in cetaceans. Death of cetaceans due to non-infectious natural disease was rarely observed in the Pacific Islands strandings with exception of dystocia, premature birth and pregnancy related pathologies. Non-infectious causes of death include chronic encephalopathies, neoplasia and metabolic disease. Acute events such as hemorrhage and gas embolism may be due to trauma or other causes (Giorda et al. 2017, Diaz-Delgado et al. 2018).

Toxoplasmosis

Spinner dolphins, *S. longirostris*, a near-shore dolphin species that form large pods off the Hawaiian Islands were the most common species recovered for examination between 2006 and 2022. Cause of death was determined in more than half of examined cases. Advanced molecular diagnostic tests such as PCR and qPCR have improved pathogen detection even if gross and histological records of pathological change are limited. *Toxoplasma gondii* is mainly a terrestrial pathogen but caused fulminant disseminated disease in three dolphins, two in different years on O‘ahu, and one animal that stranded on the island of Hawai‘i (Migaki et al. 1990, Landrau-Giovannetti et al. 2022). The same *Toxoplasma* genotype that infected and led to death of one animal in O‘ahu and the animal that stranded on Hawai‘i Island was detected in feral pigs in O‘ahu (Dubey et al. 2020). This genotype is of mild virulence in mice (Dubey et al. 2020), but the risk of severe disease after infection may differ in other host species. *T. gondii* is the most significant disease threat to endangered Hawaiian monk seals (*Monachus schauinslandi*) with this threat related to heavy runoff events (Barbieri et al. 2016, Robinson et al. 2023). Preliminary serological data indicate a high level of seroconversion in spinner dolphins and occasional positivity in other cetacean species (Traina et al. Accepted), suggesting that exposure is common. Toxoplasmosis is considered of anthropogenic source in Hawai‘i (Harting et al. 2023). Domestic cats (*Felis catus*) were introduced to Hawai‘i in the late 1700 when the first European settlers arrived and are still imported as companion animals. Studies of *T. gondii* infection of cats in Hawai‘i do not provide information about genotypes but continued introduction of novel *T. gondii* strains is likely.

Brucella

Brucella ceti has been identified as the cause of fatal meningitis, meningoencephalitis and bronchopneumonia among spinner, striped and pygmy killer whales that stranded between 2006 and 2022 (Silva-Krott et al. Submitted). *Brucella* sp. infection was believed to be responsible for mortality in a sperm whale neonate (West et al. 20215) and was detected in a humpback fetus in breech position. *Brucella ceti* groups associated with disease in marine mammals are determined by genetic analysis of cultured *Brucella* strains (Whatmore et al. 2017) and sequence analysis of the mobile element insertion sequence 711 (IS711) (Wu et al. 2017). Curtiss et al. (2022) identified ST27 as predominant in animals tested overall, including the sperm whale neonate from Hawai'i. ST27 positive animals had lesions in the lung, reproductive tract and less commonly meningoencephalitis. Dual infection of ST27 and ST23 were identified in two animals from different regions in this study, and ST26 was the main *Brucella* strain detected in stranded dolphins from the East coast of the United States where meningoencephalitis was the primary diagnosis (Curtiss et al. 2022). Infection of marine mammals by *Brucella* sp. has been associated with chronic vertebral osteomyelitis that resulted in atlanto-occipital fusion in a white beaked dolphin from Scotland (Dagleish et al. 2007). Three striped dolphins and one spinner dolphin stranded in the Pacific Islands region with atlanto-occipital fusion exhibited significant immobility of atlanto-occipital joints with brain and lung lesions. The three striped dolphins tested positive for *Brucella* sp. by PCR in multiple tissues. A draft genome of a Pacific strain of ST27 *Brucella* isolated from a captive dolphin with osteomyelitis was published by Ueno et al. 2020 and comparison with *Brucella* strains that infect Hawaiian cetaceans is needed. Further genetic analysis of Pacific *Brucella* strains would allow for investigation of strain-specific pathogenicity, tissue tropism and virulence.

Morbillivirus

A sperm whale neonate, a Fraser's dolphin, a Blainville's beaked whale and a pygmy killer whale that stranded between 2006 and 2022 suffered from morbillivirus infection in addition to brucellosis. Morbillivirus detected in tissues of a Longman's beaked whale that stranded in 2010 was classified as a novel Beaked Whale morbillivirus (West et al. 2013, Jacob et al. 2016). The same virus was detected in tissues from 12 additional species that did not necessarily have accompanying pathology during an archival screening effort that included samples collected since 1998 (Jacob et al. 2016). A Fraser's dolphin carcass recovered from Maui in 2018 resulted in the discovery of another novel strain, Fraser's Dolphin morbillivirus, that was genetically distinct from previously described dolphin and beaked whale morbilliviruses (West et al. 2021) and has since been detected in a pygmy killer whale. Cetacean morbilliviruses have been linked to an unusual mortality event of more than 200 Guiana dolphins in Brazil in 2017 (Groch et al. 2018) and are considered endemic in the Central and North-East Atlantic, causing infection in multiple species of dolphins and whales. Characteristic lesions in animals that died of cetacean morbillivirus infection include interstitial pneumonia, lymphadenitis, lymphoid depletion and nonsuppurative meningoencephalitis (Van Bressen et al. 2014). Morbillivirus effects on the immune system has been examined in cetaceans that died of the disease and immuno-depletion has been described (Diaz-Delgado et al. 2019). Depletion of immune cells in lymph nodes is observed in tissues of animals with morbillivirus infection, and multiple co-infections and chronic disease are common. Co-infections were observed and documented in the Pacific Islands stranding cases, including the morbillivirus positive Longman's beaked whale, sperm whale neonate and the Fraser's dolphin (West et al. 2013, West et al. 2015, West et al. 2021). These same individuals also tested positive for herpesvirus (West unpublished data) and circovirus in multiple tissues by PCR (Clifton et al. 2023).

Herpesvirus

Alpha and gamma herpesvirus were detected in 11.6% of 101 brain samples of five different species of odontocetes that stranded in the Canary Islands between 1996 and 2018 and two dolphins that stranded in Andalusia. Significant pathological changes observed were necrotizing encephalitis with viral intranuclear inclusions. Co-infections by dolphin morbillivirus and/or *Staphyloccoccus aureus* and in one case *Brucella sp*. contributed to death in 41% of cases where herpesvirus was detected (Sierra et al. 2022). Herpesvirus infection did not lead to death in stranded cetaceans where stranding investigations have been conducted to date in the Pacific Islands, but co-infections by herpesvirus have been detected across several species. Another non-lethal case of herpesvirus infection was a case of chronic proliferative dermatitis near the genital slit of a melon-headed whale stranded in Hawaiian waters. Histological samples showed characteristic intracytoplasmic viral inclusions and the tissue tested positive for herpesvirus by PCR but an additional five tissues examined from this animal tested negative and we assume that the infection was localized and not the cause of death.

Circovirus

Circoviruses are small non-enveloped DNA viruses that are found in many different animal species and cause chronic wasting disease in birds and domestic animals. Beaked whale circovirus was first discovered in a Longman's beaked whale that stranded in Hawaiʻi in 2010 (Landrau-Giovanetti et al. 2020) and has since been detected in tissues from an additional 10 odontocete species that stranded or were by-caught across the Pacific basin with a positive case dating back to 2000 (Clifton et al. 2023). The health impact of circovirus infection on marine mammals is unknown, however, one animal was a by-caught false killer whale in good body condition. Three other circovirus positive animals were co-infected with morbillivirus and *Brucella* sp. Circovirus infection has been associated with cardiac inflammation, enteric disease, wasting disease and reproductive problems in other species (Clifton et al. 2023).

Mycoplasma

A novel pathogen in the Pacific that contributed to respiratory disease in melon-headed whales is *Mycoplasma* sp. We confirmed the first *Mycoplasma* infection in the Pacific Islands in a melon-headed whale calf that died of interstitial pneumonia in 2011. *Mycoplasma* was detected in stranded harbor porpoises and a Sowerby's beaked whale in Scotland and a role in pneumonia was suggested (Foster et al. 2011). *Mycoplasma* was cultured and detected by molecular methods in two bottlenose dolphins and a Gervais beaked whale in Florida, where all animals died of respiratory disease, and had multiple co-infections and heavy parasitism (Paige-Karjian et al. 2021). Testing of additional Pacific Islands stranding cases with respiratory disease would aid in determining the prevalence of *Mycoplasma* infection from cetaceans in this region of the world.

Other fungal and bacterial pathogens

Of the melon-headed whales that stranded in Hawaiʻi one died of fungal pneumonia caused by *Aspergillus* sp., and one animal died of sepsis suggestive of immunosuppression. A second case of fungal disease, fatal systemic *Cryptococcus* caused death of a spinner dolphin in 2008 (Rotstein et al. 2010). Localized *Paracoccidoides ceti* infection was found in a Fraser's dolphin that stranded and was euthanized. The fungal infection was an incidental diagnosis. Fatal bacterial infection and septicemia was noted in several cases, with primary bronchopneumonia in a dwarf sperm whale, pygmy killer whale, bottlenose dolphin and Blainville's beaked whale. It is possible that the septicemia that resulted in death was secondary to another pathogen.

Mastitis was observed in a spinner dolphin and orchitis in a rough-toothed dolphin. Septicemia due to gram negative bacterial pathogens including *Erysopelothrix rhusopathiae* has been reported in bottlenose and spotted dolphins (Diaz-Delgado, 2018). We did not isolate this pathogen from animals that had lesions consistent with septicemia but identified *Proteus* and *Enterococcus* in tissue samples from a humpback calf. *Edwardsiella tarda*, a gram negative facultative anaerobic bacteria found in marine and freshwater environments was cultured from two pygmy killer whales with septicemia. Sepsis in a sperm whale due to *E. tarda* was reported by Cools et al. (2013). *E. tarda* has been isolated from suppurative infections of humans that have underlying disease, most often cancer and can cause fatal infections (Hasegawa et al. 2022).

Parasitic Disease

Metazoal parasites are commonly found in cetaceans but are not typically associated with significant pathological changes. Severe helminth infestations occur in cetaceans in poor body condition and may have another primary disease leading to immunosuppression, such as morbillivirus infection. Parasitism can be fatal if there is extensive tissue destruction, or vital organs such as the brain or inner ear are affected. Pseudaliid nematodes that infect cetaceans include *Stenurus* and *Halocercus* species, and the organs where infection is most often observed are the pterygoid sinuses and lungs (Saldana et al. 2022). Verminous pneumonia due to *Halocercus* sp. infection and obstruction of bronchi caused death in a pilot whale calf in 2022 and is suggestive of trans-placental or trans-mammary transmission. *Halocercus* adults were found in the respiratory tract of two newborn Orca calves that is consistent with direct mother-to-calf transmission (Reckendorf et al. 2018).

Severe nematodiasis of pterygoid sinuses was observed in pygmy sperm whales, pilot whales, false killer whales and melon-headed whales. It is not known if these nematode infestations directly led to death, however, bone erosion and severe sinusitis infection have been documented in stranded Risso dolphins due to *Crassicauda grampicola* infestation (Cuvertoret-

Sanz et al., 2020). Trematodiasis, presumably *Nasitrema* was detected in the bile duct and pancreatic ducts of a spinner dolphin in poor nutritional status that died in a fishery interaction. Gastrointestinal parasitism is common across all cetacean species that were examined in this study and is primarily due to *Anisakis* sp. in the glandular stomach, often associated with limited gastric erosion. *Acantocephala* sp. were detected in the gastrointestinal tract of an Orca that stranded in 2008 and was in poor nutritional condition. Cestode larvae are commonly observed within blubber but not considered pathogenic. An adult cestode was found in the small intestine of the spinner dolphin calf that died of disseminated toxoplasmosis (Landrau-Giovanetti et al. 2022).

Severe renal crassicaudiasis and evidence of verminous arteritis was noted in five Cuvier's beaked whales stranded across the Pacific Islands, including Hawaiʻi, Guam, Saipan and Wake Island. Severe arteritis of mesenteric, abdominal aorta and renal arteries and granulomatous nephritis was noted in 13 beaked whales that stranded in the Canary Islands between 2008 and 2014 and could have led to vascular impairment and death (Diaz-Delgado et al. 2016). However, renal crassicaudiasis has been reported in almost all presumed healthy adult Baird's beaked whales examined in Japanese fishery (Brownell Pers. Comm.). Renal crassicaudiasis was severe in the Pacific Islands Cuvier's beaked whale strandings but may be an incidental finding based on the high prevalence observed in the Baird's beaked whales taken in the Japanese fishery. Mild ectoparasitism, specifically by penaeid crustaceans, sea lice and barnacles were noted in stranded cetaceans, but infestations were mild and did not contribute to disease or death.

4.2 Anthropogenic Impacts

Causes of death resulting from human activities include ship strikes that may be associated with commercial, military or recreational vessel traffic and fishery interactions. Marine debris and climate change are becoming increasingly recognized threats to cetaceans (Roman et al. 2020, Gulland et al. 2022). In our Pacific Islands study, traumas were observed in 30.2% of necropsied cetaceans which is assumed to be due to anthropogenic cause although we cannot rule out extreme cases of intra- or inter-species aggression resulting in blunt trauma. A retrospective study of pathology secondary to known inter or intra-species aggression involving cetaceans described skin and soft tissue lesions and fractures in the thoracic region in animals in good body condition with full stomachs (Puig-Lozano et al. 2020). Based on these criteria we did not observe conclusive inter- or intra-species aggression leading to death in the cases examined in this study. Non-lethal intra- and inter-species aggression was observed routinely in stranded animals examined in the Pacific Islands and consisted of rake marks and superficial soft tissue injury.

Anthropogenic cause of strandings in the Pacific Islands is comparable to findings from other regions of the world. Diaz-Delgado et al. (2018) reported that cause of death due to human activities comprised 19% of stranded cetaceans examined in the Canary Islands between 2006 and 2012. Li et al. (2021) analyzed 13 years of cetacean strandings in Taiwanese waters and found anthropogenic cause in 11% of examined deaths. Examination of cetacean strandings in South Australia between 1881 and 2008 included review of records for 315 cases since 1990 and anthropogenic cause of death was recorded in 41% of the cases (Segawa & Kemper, 2015). Threats to cetacean health resulting from anthropogenic activities such as vessel strikes and human induced climate change on marine ecosystems has led to increased strandings of large whale species on the West coast of the United States (Oldach et al. 2022, Rockwood et al. 2017).

Underwater noise

Deployment of high-power seismic air guns to conduct ocean surveys and military training and testing that uses mid- to low-frequency sonar may injure cetaceans and cause strandings

(Southall et al. 2013; NOAA 2002). Mass strandings of beaked whales were rare prior to deployment of naval sonar at low to mid frequencies (Bernaldo de Quiros et al. 2019). Specific pathological changes in stranded animals associated with sonar injury in the Canary Islands, Almeria and Greece include microhemorrhages in multiple organs including acoustic fat, gas bubbles in multiple tissues due to decompression sickness and hyaline myonecrosis. Seven criteria have been developed based on examination of mass stranded Cuvier's beaked whales associated with sonar in the Canary Islands, Almeria and Greece where all seven diagnostic criteria were observed and single stranded fresh Cuvier's that died of other natural and anthropogenic causes had 1-6 of the diagnostic criteria but not all seven (Bernaldo de Quiros et al. 2019).

We applied the diagnostic criteria in six of our cases of Cuvier's beaked whales that were fresh dead and recovered in Hawaiʻi and Mariana Islands. Cuvier's beaked whales in the Pacific Islands did not exhibit all 7 diagnostic criteria in any of our cases. However, we did not examine carcasses grossly for gas bubbles in vasculature that could be distinguished from decomposition and carcass condition at time of examination and preservation of samples may have limited our ability to detect the other 6 diagnostic criteria. Two of the Guam strandings and one mass stranding in Saipan (two animals) were associated temporally with naval exercises (Simonis et al. 2020). In the case of the Saipan mass stranding, only the head was retained and examined in one case, but necropsies were conducted for the other Saipan animal and the two Guam individuals. The necropsied individuals exhibited 3-5 diagnostic criteria of the 6 diagnostic criteria examined. Significant hemorrhages in the brain and/or sound channels were observed in the three necropsied Cuvier's beaked whales that stranded in the Mariana's that co-occurred with sonar and one of the whales that stranded in Guam had significant hyaline degeneration and microscopic hemorrhages in the heart and lung.

Rapid ascent of deep diving cetaceans can be followed by decompression sickness that may be fatal (Fernandez et al. 2017). Gas accumulation in tissues observed at necropsy included gas bubbles in mesenteric and meningeal vasculature that is consistent with decompression sickness. Significant gas bubbles in the vasculature were observed during necropsy of well-preserved cases representing a Fraser's dolphin, a spotted dolphin and a pygmy sperm whale that also had a compound cervical fracture that led to death.

Acoustic trauma in cetaceans has been associated with mid-frequency sonar and underwater explosions (Parsons et al. 2017, Bernaldo de Quiros et al. 2019, Siebert et al. 2022). The first recognition by the United States government of the link between mid-frequency sonar and mass strandings occurred following a highly publicized stranding event that included Cuvier's beaked whales, Minke whales and a Blainville's beaked whale in the Bahamas in 2000 (NOAA, 2001). Hemorrhage near or around the ears was reported in 4 of 5 beaked whales examined in the Bahamas event and CT scans of the heads of the two freshest specimens indicated hemorrhage in the cochlear duct and temporal sub-arachnoid tissues (NOAA, 2001). Hemorrhage near the ears was documented in the four Cuvier's beaked whales in Guam and Saipan that stranded with a temporal association to sonar activity in the area (Simonis, 2020). Subarachnoid hemorrhage and/or microvascular injury and hemorrhage in acoustic fat are recorded in these cases where the 7 diagnostic criteria of sonar injury have been applied (Bernaldo de Quiros et al. 2019). CT scans of the head were conducted following freezing for one of the Guam beaked whales that stranded in temporal association to sonar and for an American Samoa Cuvier's beaked whale and for a fresh dead Blainville's beaked whale, Cuvier's beaked whale and Longman's beaked whale that stranded in Hawai‘i. However, CT scanner settings were optimized to detect bone tissue abnormalities and hemorrhage in the inner ears could not be fully evaluated from the scans.

A more recent technique to investigate inner ear hair cell damage associated with acoustic trauma has been developed using scanning electron microscopy (SEM) but requires removal of the ears and application of a highly specialized inner ear perfusion technique within 18 hours of death (Morell et al. 2015). Distinguishing between normal variability and hair cell death using SEM also requires comparative descriptions of normal morphological features and natural variations that occur between species (Morell et al. 2021). The SEM technique to detect hair cell death was not utilized during beaked whale strandings occurring in the Hawaiian and Mariana Islands between 2006 and 2022. The SEM technique would have only been applicable to the later strandings in the 2006-2022 timeframe. No beaked whales stranded in Hawaiʻi where time of death could be confirmed within 18 hours of ear removal, and personnel trained in the specialized perfusion technique were unable to reach Guam quickly enough to conduct inner ear preservation when a Cuvier's beaked whale stranded in 2019. Acoustic trauma was not detected in three of five pilot whales mass stranded in Kauaʻi in 2017 where inner ear perfusion was conducted for SEM analysis, but age-related hearing loss was identified in an older individual.

Blast trauma

Blast injury is believed to be characterized by significant macro and microhemorrhages in multiple tissues and acute death by direct injury, or later death due to loss of hearing. Siebert et al. (2022) described pathological findings in 24 harbor porpoises that stranded dead after controlled explosions of World War II underwater mines in the Baltic Sea. Direct injury from shock waves caused soft tissue damage leading to macro and micro hemorrhages in multiple organs including the melon and acoustic fat and fractures of auditory ossicles. Three Fraser's dolphins that stranded on two consecutive days and within a 2-mile distance of one another in 2021 were part of an

Uncommon Stranding Event. Necropsy and histopathological findings were consistent with blast injury where we observed macro and microhemorrhages in multiple organs and fractures of the auditory ossicles among the three Fraser's dolphins examined that are similar to the harbor porpoises (Siebert et al. 2022). The source of the blast trauma in the Fraser's dolphins Uncommon Stranding Event is undetermined. Possibilities include military exercises, underwater mining, fishing, construction and an unplanned explosion of underwater ordnance.

Vessel Strikes

Blunt trauma caused death in 15.1 % of all strandings with a diagnosis or diagnoses in this study. Compound fractures of cervical and thoracic vertebrae and the occipital bone of the skull were believed to be associated with vessel strikes based on the force required to result in such severe injury. Recreational boating has led to propeller injury of dolphins and is suspected as the cause of a traumatic brain injury that led to the death of a humpback calf in an area of frequent recreational boating off of the island of Oʻahu. A North Atlantic right whale unusual mortality event (2017-2023) documented vessel strike and entanglement in 21 out of 105 examined cases. Examination of 105 out of 209 dead humpback whales during the North Pacific 2016-2023 humpback whale unusual mortality event revealed pre-mortem vessel strikes in approximately 40% of the cases (NOAA 2023). An adult pygmy sperm whale that stranded in 2021 on Kauaʻi had a comminuted fractures of axis and mandibular rami. It is likely the animal surfaced, suffered from decompression sickness, and then experienced a vessel collision leading to instant death.

Fishery Interactions

Many animals that are necropsied have signs of fishery interaction including scars in the mouth and on fins from hooks, but these injuries rarely lead to cause of death. A pelagic false killer whale was by-caught and had ingested a Mahi Mahi that was hooked on the fishing line. Death occurred due to entrapment. A stranded bottlenose dolphin in advanced decomposition had a penetrating fishhook in the esophagus that could have limited prey ingestion and led to infection and death. Fishery interaction was the most common cause of death in striped dolphins and bottlenose dolphins that stranded on the coast in Catalonia between 2012 and 2019 (Cuvertoret-Sanz et al. 2020). Fishery interactions threaten dolphin species and endangered insular main Hawaiian Island false killer whales.

The most common cause of human activity related death in South Australia between 1881 and 2008 was entanglement, described from 66 known instances and 37 probable instances (Segawa & Kemper 2015). Among our stranding cases, four dolphins died of entanglement (Table 5). On average seven humpback whales with non lethal entanglement were reported to the Hawaiian Island Humpback whale sanctuary each year between 2002 and 2017 (Lyman 2017). One whale was carrying gill nets from higher latitudes and pot gear from British Columbia (Bradford & Lyman 2020).

Other anthropogenic traumas

Isolated cases of anthropogenic trauma included a harpoon abdominal injury followed by infection and death in spinner dolphin recovered dead in Kauaʻi, and a potential gunshot injury of a Fraser's dolphin recovered in Guam. Plastic debris ingestion was noted in a diverse number of species but typically involved small pieces that did not cause gastric obstruction. Significant plastic debris was found in three pilot whales that stranded on different islands in disparate years but did not contribute to the death of the animals. Plastic debris ingestion has been documented in 81 of 123 marine mammal species examined after stranding world-wide. Mortalities are due to obstruction or perforation followed by peritonitis and septicemia, but also starvation if the digestive process is significantly impaired (Roman et al. 2020). Flexible plastics including plastic bags/sheets/rope/fishing gear are a significant portion of plastic debris and the cause of the majority of deaths (Romam et al. 2020). Rope and netting constituted a significant percentage of plastic debris found in the stomachs of stranded cetaceans in this study of the Pacific Islands.

5. CONCLUSION

This report describes pathological findings and cause of death in 126 out of 196 stranded cetaceans where full or partial necropsies were performed between 2006 and 2022. The low recovery rate and examination of carcasses after death limits inference of species vulnerability to specific anthropogenic and disease threats, especially as strandings discussed in this report cover a wide geographic region.

Natural and infectious disease was documented in the majority of cases examined. The spread of novel pathogens among Pacific Island cetaceans to insular species of small population sizes with a low number of breeding individuals poses a significant conservation threat. Thirty percent of strandings with significant pathological findings were the result of trauma. Anthropogenic impacts were the most likely cause of death in most trauma cases including vessel strikes, fishery interactions, and blast and sonar injury. Full stranding investigations are the only means to identify specific causes of death, to investigate morbidity in cetaceans and to evaluate threats through quantitative means. Over time and through continued investigative efforts, data on marine debris ingestion in stranded cetaceans will contribute to a broader understanding of marine pollution impacts on protected and endangered species. Continued stranding investigations are critical to monitoring the impact of natural and anthropogenic threats affecting marine mammals, that serve as recognized sentinels of ocean health.

6. ACKNOWLEDGMENTS

We are grateful to the Pacific Islands Marine Mammal Stranding Response Network of volunteers for conducting stranding response, recovery and transport of cetacean carcasses for necropsy across the Pacific basin. We thank Brent Tibbatts for leading cetacean necropsies in Guam and Alan Tagarino, Michael Marsik and Adam Miles for collecting samples of stranded cetaceans in American Samoa. We would like to acknowledge Nicholas Hofmann and the necropsy team at the Health and Stranding Lab. We are grateful to Jana Phipps for assistance with manuscript figures and tables. All work was conducted under NOAA National Marine Fisheries Service permit #18786-06. Funding for stranding response and necropsy operational support was received from the NOAA John H. Prescott Marine Mammal Rescue Assistance Program over many years between 2006 and 2022. We are also grateful to HDR and the US Commander Pacific Fleet Environmental Readiness Division for funding this project.

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Table 1. Summary of stranding case demographics between 2006-2022

Species	Total Cases Examined	Necropsy Status			Sex			Age Classes Represented			
		Full	Partial	Minimal	Male	Female	Unknown	Calf	Juvenile	Adult	Unknown
Balaenoptera brydei	3	0	0	3	1	0	2	0	0	1	2
Feresa attenuata	10	10	0	0	5	5	0	2	2	6	0
Grampus griseus	3	2	0	1	1	1	1	0	0	2	1
Globicephala macrorhynchus	17	13	0	4	6	4	7	1	3	6	7
Indopacetus pacificus	1	1	0	0	1	0	0	0	1	0	0
Kogia breviceps	19	17	0	2	8	10	1	0	2	16	1
Kogia sima	8	7	1	0	5	2	1	0	2	6	0
Lagenodelphis hosei	7	7	0	0	5	2	0	0	1	6	0
Megaptera novaeangliae	25	15	2	8	6	11	8	17	0	5	3
Mesoplodon densirostris	5	3	0	2	3	2	0	0	2	1	2
Orcinus orca	2	1	0	1	1	0	1	0	0	2	0
Peponocephala electra	20	16	0	4	11	6	3	6	5	7	2
Physeter macrocephalus	27	1	3	22	5	2	20	3	0	11	13
Pseudorca crassidens	8	7	1	0	4	3	1	0	1	6	1
Stenella attenuata	6	7	0	0	4	2	0	2	1	3	0
Stenella coeruleoalba	26	25	0	1	15	10	1	2	16	8	0
Stenella longirostris	42	40	1	1	20	16	6	14	11	14	3
Steno bredanensis	4	3	0	1	2	1	1	0	2	2	0
Tursiops truncatus	5	5	0	0	2	1	2	1	1	3	0
Ziphius cavirostris	12	8	0	4	9	1	2	1	5	3	3
Total	**250**	**188**	**8**	**54**	**114**	**79**	**57**	**49**	**55**	**108**	**38**

Table 2. Pathology Summary 2006-2022

Species	Pathological Categories									Total
				Trauma						
	Natural - Good Nutrition	Natural - Poor Nutrition	Perinatal /Neonatal	Blunt Trauma (includes blast trauma)	Fishery Bycatch	Fishery Injury (hooks, ingestion of nets, gun-shot etc.)	Entrapment, entanglement	Decompression	Undetermined	
Balaenoptera brydei									3	3
Feresa attenuata	3	5							2	10
Globicephala macrorhynchus	5		1	1		3		1	6	17
Grampus griseus		1				1			1	3
Indocetus pacificus	1									1
Kogia breviceps	5	2		5				1	6	19
Kogia sima	1	1					1		5	8
Lagenodelphis hosei	1	2		3		1				7
Megaptera novaeangliae	1		5**	1					19	26
Mesoplodon densirostris		1							4	5
Orcinus orca		1							1	2
Peponocephala electra	3	6	2						9	20
Physeter macrocephalus			2						26	27
Pseudorca crassidens	3	1			1				3	8
Stenella attenuata	2	1	2**				1	1		7
Stenella coeruleoalba	7	8		1				1	9	26
Stenella longirostris	2	8	6**	1		1	2		23	43
Steno bredanensis		1			2		1			4
Tursiops truncatus	1					1			2	4
Ziphius cavirostris	5			7					5	12*
Total	**40**	**38**	**16**	**19**	**3**	**7**	**5**	**4**	**124**	**258**

*Z. cavirostris, 5 of the 7 animals with trauma had significant natural disease and were in good body condition and are only counted once in the total.
**Lists mother as natural disease/good body condition and fetus under perinatal/neonatal category.

Table 3. Main morphological and etiologic diagnoses in animals included in 'pathology associated with good nutritional status'

Pub ID	Species	Morphologic diagnoses	Etiologic diagnoses
FA-9239	*F. attenuata*	Chronic-active pleuropneumonia, epicarditis, myocardial atrophy and degeneration, hepatic lipidosis	Bacterial septicemia and pleuropneumonia
FA-6436	*F. attenuata*	Lymphocytic meningitis, fibrinous, pyogranulomatous bronchopneumonia, chronic lymphadenitis	Infectious meningitis and bronchopneumonia, parasitic pyogranulomatous pneumonia
FA-9529	*F. attenuata*	Lymphadenopathy, fibrinous bronchopneumonia	Infectious lymphadenopathy, bacterial bronchopneumonia
FA-9519	*F. attenuata*	Acute pterygoid sinusitis	Verminous pterygoid sinusitis
FA-8456	*F. attenuata*	Bronchointerstitial pneumonia, lymphadenopathy	Infectious pneumonia
GM-3500	*G. macroryhnchus*	Systemic gas embolism, granulomatous gastritis, pericystitis, myocarditis	Gas embolism, systemic parasitosis
GM-1694	*G. macroryhnchus*	Non-suppurative meningoencephalitis, pterygoid sinusitis and facial contusion	Infectious meningoencephalitis, pterygoid and facial trauma
GM-8865	*G. macroryhnchus*	Pterygoid sinusitis, ulcerative gastritis, parasitic dermatitis	Verminous pterygoid sinusitis, gastric nematodiasis, cutaneous phyllobothriosis
GM-5331	*G. macroryhnchus*	Pterygoid sinusitis and gastritis	Verminous pterygoid sinusitis, verminous gastritis
GM-5665	*G. macroryhnchus*	Ulcerative gastritis, mucometra, pterygoid sinusitis, retroperitoneal hematoma	Verminous pterygoid sinusitis, verminous gastritis, traumatic retroperitoneal hematoma
GM-4462	*G. macroryhnchus*	Pterygoid sinusitis, pulmonary edema, focal glossitis	Traumatic and stress related pulmonary edema (stranding event), verminous pterygoid sinusitis
GM-3151	*G. macroryhnchus*	Pterygoid sinusitis, ulcerative gastritis, dermatosis	Verminous pterygoid sinusitis and gastritis, dermatitis by Xenobalanus
IP-4830	*I. pacificus*	Open mandibular and maxillary fracture, subacute encephalitis, fibrinous pneumonia, periglomerulonephritis, lymphoid depletion, multifocal non-suppurative myocarditis	Viral encephalitis, bacterial pneumonia, septicemia, maxillary and mandibular fracture (trauma), infectious multifocal myocarditis
KB-9806	*K. breviceps*	Bilateral mandibular and palatine fracture, verminous gastritis, glomerulopathy	Verminous gastritis, glomerulopathy, perimortal mandibular and palatine fractures
KB-1608	*K. breviceps*	Chronic gastritis, dermatosis, pulmonary edema	Verminous gastritis, cutaneous phyllobothriosis, pulmonary edema (trauma)

KB-8100	*K. breviceps*	Chronic gastritis	Verminous gastritis
KB-3756	*K. breviceps*	Chronic gastritis, dilated cardiomyopathy, mandibular fracture (perimortal)	Verminous gastritis, dilated cardiomyopathy, muscular endoparasitism (sarcocystis), perimortal mandibular fracture (trauma)
KB-5110	*K. breviceps*	Cardiac tamponade, chronic gastritis	Cardiac tamponade (cardiomyopathy), verminous gastritis
KS-8329	*K.sima*	Multifocal myocardial fibrosis and hypertrophy	Cardiomyopathy of unknown origin
MN-6969	*M. novaeangliae*	Dystocia	Dystocia (breech birth)
PC-5516	*P. crassidens*	Pulmonary and cardiac fibrosis	Cardiac failure of unknown origin
PC-5206	*P. crassidens*	Gastric foreign bodies, pterygoid sinusitis	Verminous pterygoid sinusitis, intestinal acanthocephaliasis
PC-3118	*P. crassidens*	Pterygoid sinusitis	Verminous pterygoid sinusitis
PE-3796	*P. electra*	Interstitial pneumonia	Infectious pneumonia
PE-6633	*P. electra*	Lypmphadenopathy	Infectious lymphadenopathy
PE-1540	*P. electra*	Interstitial pneumonia, non-suppurative meningitis, chronic gastritis	Infectious pneumonia and meningitis, parasitic gastritis, and lymphadenitis
SA-3674	*S. attenuata*	Pneumonia	Verminous and bacterial pneumonia
SA-8182	*S. attenuata*	Dystocia	Dystocia
SC-9107	*S. coeruleoalba*	Non-suppurative meningoencephalitis, granulomatous bronchopneumonia	Neurobrucellosis, infectious bronchopneumonia
SC-3597	*S. coeruleoalba*	Meningitis, pulmonary fibrosis, cervical vertebral fusion	Infectious meningitis
SC-1774	*S. coeruleoalba*	Meningitis, granulomatous lymphadenitis (eosinophilic)	Infectious meningitis, endoparasitism
SC-9761	*S. coeruleoalba*	Meningitis, lymphadenopathy	Neurobrucellosis
SL-7063	*S.longirostris*	Dystocia	Dystocia
TT-4860	*T. truncatus*	Hepatitis and pancreatitis	Infectious (bacterial) hepatitis, pancreatitis, endotoxemia
ZC-8534	*Z. cavirostris*	Vasculitis, nephropathy	Systemic parasitosis (vascular and renal), Crassicaudiasis
ZC-1099	*Z. cavirostris*	Suppurative bronchopneumonia, nephropathy	Infectious bronchopneumonia, renal Crassicaudiasis
ZC-4990	*Z. cavirostris*	Vasculitis, nephropathy	Renal Crassicaudiasis

Table 4. Main morphological and etiologic diagnoses in animals included in 'pathology associated with poor nutritional status'

Pub ID	Species	Morphologic diagnoses	Etiologic diagnoses
FA-7449	*F. attenuata*	Kachexia, hepatic lipidosis and glycogenosis	Undetermined
FA-2937	*F. attenuata*	Lymphocytic meningitis, focal granulomatous gastritis	Neurobrucellosis, parasitic gastritis
FA-7995	*F. attenuata*	Lymphocytic meningitis, interstitial pneumonia, myocarditis	Neurobrucellosis, bacterial pneumonia
GG-7370	*G. griseus*	Dilated cardiomyopathy, ulcerative gastritis	Hepatic and gastric parasitosis
KB-5948	*K. breviceps*	Dilated cardiomyopathy, mandibular fractures, bilateral	Dilated cardiomyopathy, perimortal mandibular fracture
KS-8901	*K.sima*	Bronchopneumonia, ulcerative gastritis	Bronchopneumonia, bacterial septicemia
LH-2283	*L. hosei*	Subcutaneous phyllobothriosis, hepatic telangiectasia, chronic lymphadenitis, microhemorrhages	Systemic viral infection, kachexia, phyllobothriosis
LH-1112	*L. hosei*	Focal granulomatous dermatitis, lymphadenopathy, encephalopathy with multifocal neuronal loss, microgliosis and lipofuscinosis	Fungal dermatitis (Lobomycosis-like disease), chronic encephalopathy
MD-2108	*M. densirostris*	Pyogranulomatous pneumonia, ulcerative, perforating gastritis, acute renal tubular necrosis, mandibular fracture associated with hemorrhage (perimortal)	Fungal pneumonia (Aspergillosis), viral infection
PC-6644	*P. crassidens*	Endocardiosis (L AV valve), necrotizing adrenalitis, interstitial pneumonia, renal pigmentary nephrosis, necrosuppurative conjunctivitis	Infectious pneumonia, endocardiosis
PE-3796	*P. electra*	Interstitial pneumonia	*Mycoplasma sp.*
PE-8824	*P. electra*	Granulomatous pneumonia	Fungal pneumonia (Aspergillosis)
PE-7757	*P. electra*	Interstitial pneumonia, chronic pancreatitis	Infectious pneumonia (bacteria, virus), pancreatic trematodiasis
PE-6423	*P. electra*	Non suppurative meningitis, meningeal fibrosis, pterygoid sinusitis	Verminous pterygoid sinusitis, infectious meningitis
PE-5132	*P. electra*	Lymphadenopathy, pulmonary fibrosis, pterygoid sinusitis	Verminous pterygoid sinusitis, systemic parasitosis, infectious pneumonia
PE-7548	*P. electra*	Pneumonia, sinusitis, septicemia - fetal membranes?	Verminous pterygoid sinusitis, septicemia
SA-9230	*S. attenuata*	Pneumonia, renal disease, bone disease (fracture?)	Verminous bronchopneumonia (Halocerus sp.)
SB-9078	*S. bredanensis*	Orchitis, septicemia	Septicemia, pyogranulomatous orchitis, biliary cystadenoma
SC-4198	*S. coeruleoalba*	Meningitis	Infectious meningitis

SC-9044	*S. coeruleoalba*	Meningitis	Infectious meningitis
SC-6274	*S. coeruleoalba*	Cardiomegaly, atrial infarct	Cardiac arrhythmia secondary to infarct
SC-8788	*S. coeruleoalba*	Chronic pneumonia, meningoencephalitis, myocardial fibrosis	Verminous bronchopneumonia, infectious meningoencephalitis
SC-4690	*S. coeruleoalba*	Non suppurative meningitis, fusion C-1- occipital bone	Neurobrucellosis
SC-1142	*S. coeruleoalba*	Non suppurative meningitis	Infectious meningitis
SC-1763	*S. coeruleoalba*	Non suppurative meningitis	Neurobrucellosis
SC-6259	*S. coeruleoalba*	Meningitis	Neurobrucellosis
SL-6326	*S. longirostris*	Mastitis, septicemia	Septicemia secondary to mastitis
SL-8088	*S. longirostris*	Non suppurative meningitis, severe, chronic	Infectious meningitis
SL-2287	*S. longirostris*	Systemic lymphadenitis, granulomatous pneumonia	Fungal pneumonia, systemic cryptococcosis
SL-6111	*S. longirostris*	Non suppurative meningoencephalitis	Infectious meningoencephalitis
SL-2694	*S. longirostris*	Granulomatous myocarditis	Infectious myocarditis
SL-1047	*S. longirostris*	Bronchopneumonia	Bacterial bronchopneumonia
SL-4200	*S. longirostris*	Disseminated systemic necrotizing inflammation	Acute toxoplasmosis
SL-9678	*S. longirostris*	Disseminated systemic necrotizing inflammation	Acute toxoplasmosis

Table 5. Main morphological and etiologic diagnoses in animals with fishery interaction or trauma of all causes

Pub ID	Species	Morphological diagnosis	Etiological diagnosis
GG-9135	*G. griseus*	Integumentary scarring and penetrating, focal, incisive wound	Hooking injury, entanglement
GM-1721	*G. macroryhnchus*	Gastritis with foreign body, osteoporosis	Foreign material ingestion
GM-9927	*G. macroryhnchus*	Ulcerative gastritis with foreign body (20lbs)	Net and fishing gear ingestion
KB-4319	*K. breviceps*	Pulmonary edema, systemic parasitosis, verminous gastritis	Pulmonary edema (trauma), systemic parasitosis (Phyllobothriosis)
KB-9355	*K. breviceps*	Fractures, subcutaneous craniofacial hematoma, right ear, subcutaneous phyllobothriosis, verminous gastritis	Fractures and hematoma (trauma), verminous gastritis, pterygoid sinusitis
KB-2757	*K. breviceps*	Focal subcutaneous hemorrhage, systemic parasitosis, epicardial gas embolism	Subcutaneous hemorrhage (trauma), verminous gastritis, pterygoid sinusitis

KB-7347	*K. breviceps*	Multiple hemorrhages in musculature and internal organs, pulmonary edema	Hemorrhage (trauma)
KB-5324	*K. breviceps*	Bilateral mandibular comminuted fracture, comminuted axial fracture, systemic gas embolism with hemorrhage, dilated cardiomyopathy	Trauma, decompression sickness, dilated cardiomyopathy
KB-4803	*K. breviceps*	Pulmonary edema, verminous gastritis, multifocal granulomatous balanitis	Trauma, infectious balanitis, verminous gastritis
KB-7354	*K. breviceps*	Subcutaneous and muscular hemorrhage around right ear, spinal hemorrhage, incomplete squamosal fracture, unilateral pleurisy, ulcerative gastritis	Blunt trauma
KS-7686	*K. sima*	Pulmonary edema	Trauma (entrapment)
LH-2901	*L. hosei*	Compound mandibular and cervical vertebral fracture acute, with extensive hemorrhage, vascular gas embolism	Trauma, decompression sickness, blast injury
LH-4931	*L. hosei*	Compound mandibular fracture with hemorrhage, internal diffuse hemorrhages	Trauma, blast injury
LH-4050	*L. hosei*	Diffuse internal hemorrhage	Trauma, blast injury
LH-7528	*L. hosei*	Penetrating abdominal wounds (2)	Trauma (gunshot)
MN-4272	*M. novaeangliae*	Costal fracture (rib 1), muscular trauma, fibrinous, necrotizing epicarditis	Costal fracture, septicemia with intralesional bacteria
MN-3534	*M. novaeangliae*	Pulmonary edema, cranial hemorrhage, cerebral hemorrhage	Trauma
PC-4290	*P. crassidens*	Fishhook ingestion	Trauma (fishery bycatch)
SA-3595	*S. attenuata*	Nonspecific	Trauma (entanglement)
SA-1729	*S. attenuata*	Vascular gas embolism, subcutaneous hemorrhage left ventral side	Trauma, decompression sickness
SB-7956	*S. bredanensis*	Skull only, surrounded by heavy fishnet	Trauma (entanglement)
SC-6909	*S. coeruleoalba*	Occipital and mandibular fracture, hematoma	Trauma (boat)
SL-6047	*S. longirostris*	Subcutaneous hemorrhage and bruising ventrally, left	Trauma
SL-6417	*S. longirostris*	Nonspecific	Trauma (entanglement)
SL-7045	*S. longirostris*	Abdominal wound	Trauma (fishery interaction)
SL-2466	*S. longirostris*	Nonspecific	Trauma (entanglement)
TT-2908	*T. truncatus*	Fishhook ingestion	Trauma (fishhook)
ZC-8534	*Z.cavirostris*	Meningeal hemorrhage, ventricular hemorrhage, nephropathy	Trauma (acoustic, blast), renal Crassicaudiasis
ZC-4990	*Z.cavirostris*	Meningeal hemorrhage, scleral hemorrhage, nephropathy	Trauma (acoustic, blast), renal Crassicaudiasis

ZC-4990	*Z.cavirostris*	Left cerebral ventricular hemorrhage, L mandibular hematoma, nephropathy	Trauma (acoustic, blast), renal Crassicaudiasis
ZC-2247	*Z.cavirostris*	Cranial hematoma, cerebral hemorrhage, nephropathy	Trauma (acoustic, blast)
ZC-8769	*Z.cavirostris*	Cervical vertebral fracture (C1), myopathy, nephropathy	Trauma, renal Crassicaudiasis
ZC-2875	*Z.cavirostris*	Microvascular hemorrhages, multiple organs, capture myopathy heart	Trauma (acoustic, blast)
ZC-1834	*Z.cavirostris*	Cerebral hemorrhage, nephropathy	Trauma (acoustic, blast), renal Crassicaudiasis

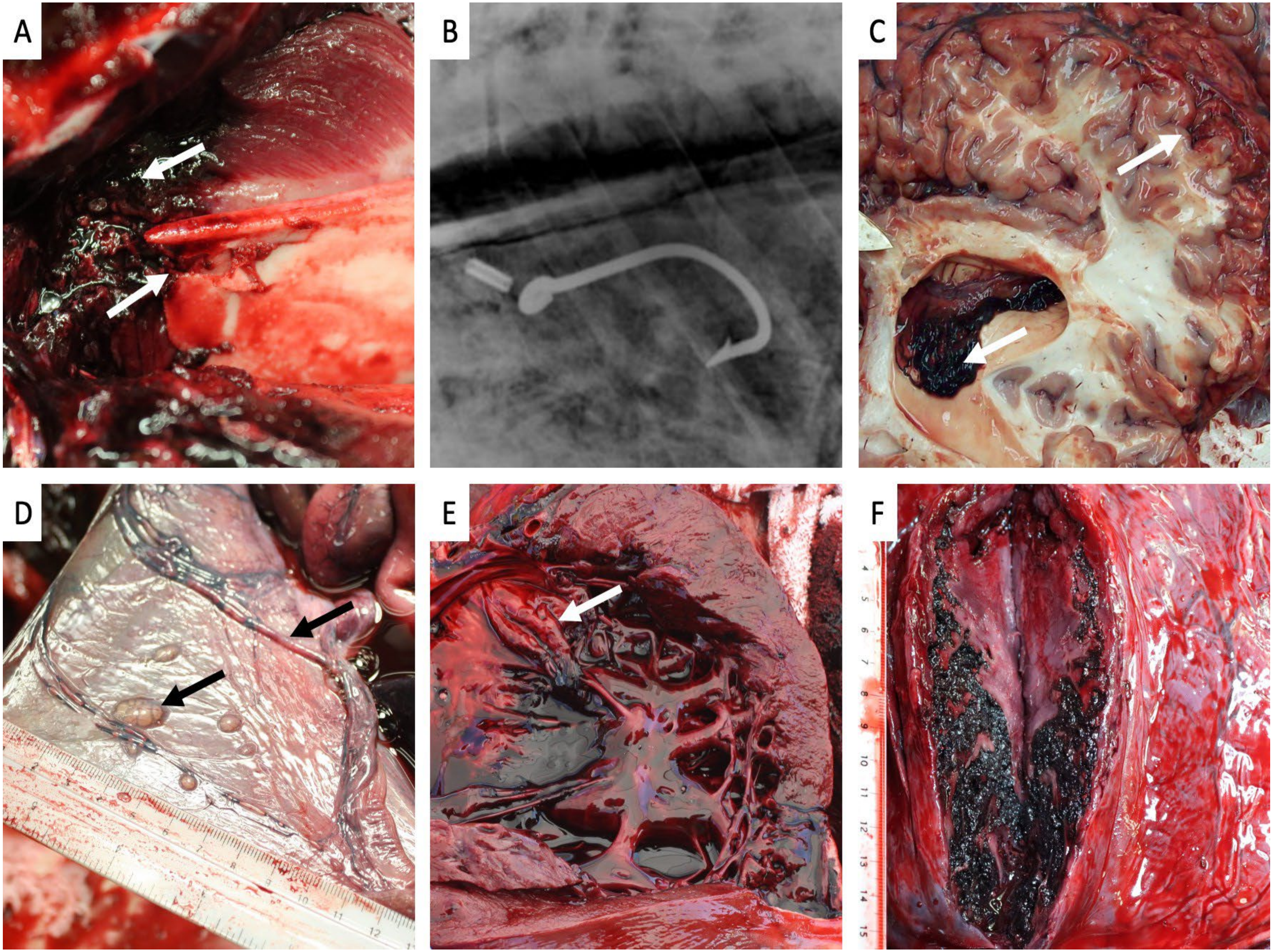
A
B
C
D
E
F

Figure 1

1A Fraser's dolphin: Trauma – mandibular compound fracture (arrow) and hemorrhage (arrow)

1B False killer whale: Fishery Interaction, x-ray – Fishhook ingestion

1C Beaked whale: Cerebral (arrow) and ventricular hemorrhage (arrow)

1D Pygmy sperm whale: Decompression sickness – mesenteric gas bubble (arrow) and venous gas bubble (arrow)

1E False killer whale: Heart – valvular endocardiosis (arrow)

1F Pygmy sperm whale: Heart – tamponade, left ventricular thrombus

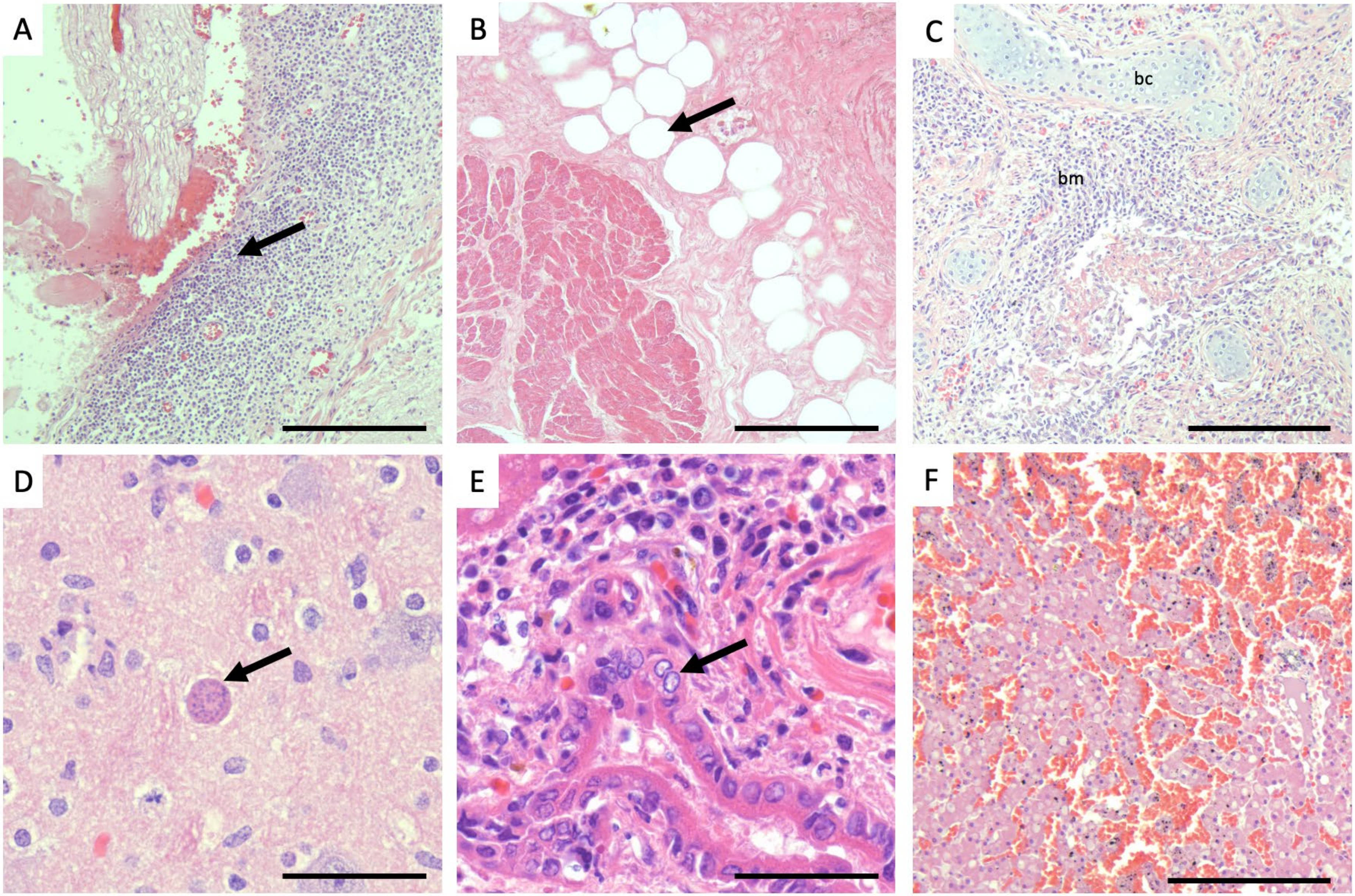
A
B
C
bc
bm
D
E
F

Figure 2

2A Striped dolphin: H&E stain. Scale bar is 2mm.Neurobrucellosis - lymphocytic meningitis (arrow)

2B Pygmy sperm whale: H&E stain. Scale bar is 2 mm. Decompression sickness- gas bubbles (arrow) in connective tissue, heart.

2C Pygmy killer whale: H&E stain. Scale bar is 2mm.Lung – Bronchopneumonia. bc – bronchial cartilage, bm- bronchial mucosa

2D Spinner dolphin: H&E stain. Scale bar is 500 µm. Toxoplasmosis – Brain, *Toxoplasma* cyst (arrow)

2E Fraser's dolphin: H&E stain. Scale bar is 500 µm. Portal hepatitis – Morbillivirus inclusions (arrow) in bile epithelia

2F Pygmy sperm whale: H&E stain. Scale bar is 2mm. Liver –hemorrhage (suspected blast injury)